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U S ARMY NATICK LABORATORIES

TECHNICAL REPORT

TS-127

BEHAVIOR OF LIQUIDS ON VARIOUS CORDS FOR SEAMS OF CHEMICAL AND BIOLOGICAL PROTECTIVE OVERGARMENTS

CLOTHING & ORGANIC MATERIALS DIVISION

OCTOBER 1963

NATICK, MASSACHUSETTS

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The results show that liquid behavior on seams differs among chemicals as well as among cords. The optimum protection for a seam may vary from one chemical to another.

1. Protective clothing
2. Clothing
3. Absorption
4. Impregnation
5. Fibers
6. Protective treatments

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BEHAVIOR OF LIQUIDS ON VARIOUS CORDS FOR SEAMS OF CHEMICAL AND BIOLOGICAL PROTECTIVE OVERGARMENTS

Pauline P. Hall
Technologist

Fabric Engineering and Finishing Branch

Project Reference:
1K6-43303-D547

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FOREWORD

The leakage of water through seams has long been studied by the Army in its quest for rainproof clothing and equipage. In addition, many researchers have reported the theories of liquid migration on and through textile assemblies. Up to this time, very little information is available of seams tested for liquid penetration by various chemicals. Knowledge from such information is important for the development of chemical and biological protective overgarments.

Technologists at these Laboratories studied seams to which liquids had been applied. From these studies, it was determined that an LSc-1 seam type with a superimposed cord will provide protection against penetration of liquids along the seams. This report relates the performances of various cords sewn on a fabric to the migration and absorption characteristics of these cords.

S. J. KENNEDY
Director
Clothing & Organic Materials Division

APPROVED:

DALE H. SIELING, Ph.D.
Scientific Director

MERRILL L. TRIBE
Brigadier General, USA
Commanding

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ABSTRACT

Previous researchers have reported the behavior of liquid migration on and through textile assemblies. This study is the first known attempt to test seams for liquid penetration by various chemicals (important for developing chemical and biological protective overgarments) and to develop an LSc type seam with a superimposed cord to help resist this penetration.

The results show that liquid behavior on seams differs among chemicals as well as among cords. The optimum protection for a seam may vary from one chemical to another.

BEHAVIOR OF LIQUIDS ON VARIOUS CORDS FOR SEAMS

OF CHEMICAL AND BIOLOGICAL PROTECTIVE OVERGARMENTS

1. Introduction

a. Review of literature

Several investigators have reviewed the theoretical and actual behavior patterns of liquids on various surfaces. Their conclusions are briefly summarized here.

Fox and Zisman (2) observed the spreading of liquids on low-energy surfaces. When a liquid dropped on a solid surface does not spread but comes to an equilibrium state, this state has been expressed by Young's equation:

$$sa = sl + la \cos \Theta$$

where:
sa = free energy of solid - air interface
sl = free energy of solid - liquid interface
la = free energy of liquid - air interface
Θ = contact angle

But Fox and Zisman showed that this equation is incorrect, since sa can be altered by the adsorption of vapor on the solid. They presented corrected equations for the adhesion of solids and liquids of low vapor pressure and of solids and systems in saturated vapor. At the same time they pointed out that it is difficult to measure the work of adhesion between solid-liquid interfaces because most pure liquids spread on most clear solids. In the literature, exceptions to this are usually limited to water or aqueous solutions on hydrophobic surfaces and to liquid metals on surfaces with which they do not alloy. These authors observed that the contact angle is lowered on rough surfaces. They concluded that there is no way of separating the free energies of the solid-liquid interface and of the solid surface itself and of relating these to the critical surface tensions of liquids.

Minor and his associates (9) postulated that the rate of wicking on a yarn varies directly with the surface tension of the liquid and the cosine of the contact angle and inversely with the viscosity. However, the contact angle may be ambiguous. In systems where there is hysteresis of this angle, an advancing angle is considered to control the forward capillary motion of the liquid over a fresh unwetted solid surface. If the contact angle hysteresis is less than 90°, the liquid movement and wicking will proceed from larger spaces to smaller ones. If the contact angle hysteresis is more than 90°, the liquid movement as well as the wicking will be inhibited. Also, higher-angle liquids are held in greater quantity by a unit length of yarn than are liquids having a lower contact angle hysteresis. The qualitative correlation between the theoretical and actual wicking rates may therefore differ among fibers and fabrics.

In another article (10), they define and describe the methods of measuring contact angles and illustrate unduloid and clamshell forms of liquid droplets on fibers. They found that the resultant forms depend on not only the contact angle but also on the volume of liquid relative to the volume per unit length of fiber.

A later study by the same authors (11) reports the capillary migration of liquids on woven and knitted fabrics. In this study the classical capillarity theory is related to the actual behavior of organic liquids within yarns:

$$s^2 = k' t$$

where:

s = height of the rise
t = time
k' = constant

Minor and his colleagues also observed the behavior of liquid transfer from one yarn to another. They noted that each yarn intersection acts as a new reservoir which feeds the branches equally and that the migration through interyarn spaces takes place from the larger to the smaller, as in the law of capillarity.

Winch (16) has set forth a theory concerning liquid absorption by capillary media. In one system he assumes that the contact angle at the liquid-solid-air interface is constant. Highly absorbent materials appear to approach this condition. In another system he assumes that the liquid is absorbed at a constant rate of linear diffusion. This flow curve may pass from an increasing rate zone into a decreasing rate zone and the surface tension, contact angle, and viscosity influence the point at which the transition occurs.

Winch states two very important general conclusions: 1) there is an optimum effective capillary diameter or pore size for the maximum rate of liquid absorption, depending on the environmental conditions; 2) caution should be exercised in the method of testing absorbent media for the rate of fluid absorption in order to avoid ranking the various media incorrectly for end-use application.

For many years the Department of the Army has studied various protective garments. Army investigators have outlined some of the theoretical and applied research factors that should be considered for such clothing.

A Quartermaster Textile Series report on water-resistant textiles (12) has defined the tenacity of a liquid to adhere to a solid as a fundamental surface property known as the "work of adhesion"(W):

$$W = so + lv - sl$$

where: so = free energy of solid surface
lv = free energy of liquid
sl = free energy of solid-liquid interface

The report states that the poorly defined nature of a fabric surface, distinguished from that of wax or glass, complicates this simple concept. It explores the thesis that the contact angle between water and fibers, together with the geometrical arrangement of the fibers in the fabric, determines both the rate and extent of wetting (absorption) and the degree of penetration. It holds that hydrophobic fiber surfaces are essential for a high contact angle and that certain arrangements of fibers are more resistant to wetting and penetration than others; the most resistant are considered those with a large number of single fibers projecting perpendicular to the plane of the fabric. The report concludes that the contact angle can be increased by changes in fabric structure and finish. However, the angle per se is not a quantitative measure of water repellency; the drop size and pore size also influence penetration. The authors felt that one of the greatest discoveries in garment design was that two layers of a water-repellent fabric afford more than twice the protection of a single layer.

In a Quartermaster study of missile fuel handler's clothing, Miles (7) states that the two most important factors that determine whether or not a liquid will wet a solid surface are the surface tension of the liquid and the free surface energy of the solid. A low surface tension but a high free surface energy will increase the wetting. He adds that other variables which may affect the contact angle are impurities, such as dirt and grease, and the roughness of the surface. Temperature must also be considered. As the temperature rises, the surface tension of the liquids decreases and the penetration increases.

Segal and his associates (13) have studied oil- and water-repellent treatments with fluorocarbon for cotton fabrics. They measured the surface tension and viscosity of selected liquids and calculated their volatility. They postulated that, when liquids of widely varying chemical structures and physical properties are placed on a porous material, surface tension is not the primary wetting factor. The volatility of the liquid also appeared to be extremely important. Fabrics are penetrated by the molecules of solvents in a vapor state, therefore the more volatile liquids penetrate fabrics more quickly.

At a symposium on the origins of resistance to toxic agents, the ability of organisms to adjust to environmental variations was defined (14) as adaptation. For example: the leaves of some plants produce waxy substances which resist the penetration of chemical sprays. Also, the roach can detoxify arsenic by complexing it with reduced glutathione. Although some low-order organisms are able to resist environmental irritation, the complex human body is not capable of providing adequate resistance to toxic agents. Environmental adaptations must be made available for this purpose, using such extraneous devices as protective clothing or reactive chemicals. Genetic adaptation or mutation is found in many low orders of organisms, such as in some bacterial strains that have been subjected to nitrogen mustards. Many other organisms adjust to the environment by interactions of a non-permanent nature; they develop induced enzyme systems in the presence of specific substrates such as toxic drugs.

Jacobs (5) found that textiles readily absorb liquid chemical agents. Most animal fibers, such as wool and silk, absorb the vapor of war gases more readily and in greater quantity than do vegetable fibers such as cotton and linen. Furthermore, animal fibers are changed very little by absorption. On the other hand, cotton fibers lose strength especially in the presence of moisture, which causes acidity and corrosion with some chemical agents (8).

b. Previous work on protective seams

The Seams Engineering Section of the Clothing and Organic Materials Division of the U. S. Army Natick Laboratories has completed some preliminary studies of chemically resistant seams (3). From this work, it was concluded that seams of an LSc-1 construction (1) with a cord sewn on (Fig. 1, a) or between (Fig. 1, b) the layers of fabric would offer some protection from chemical simulators,[1] and that modified SSa-1 seams (Fig. 2) also appear to be able to resist chemical penetration because of the layer of fabric under the main seam and the absence of any single row of stitching penetrating all layers of fabric. The disadvantage of the modified SSa-1 seams is that they require more complicated and costly methods of fabrication than the more conventional LSc-1 type of seam. For this reason, further exploration of cords for possible use in the LSc-1 type of seam construction for chemical and biological (CB) protective overgarments has been considered essential.

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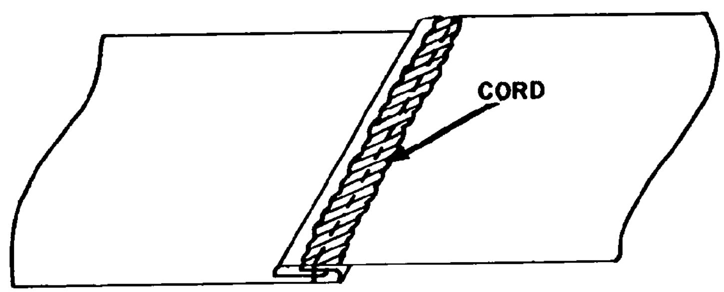
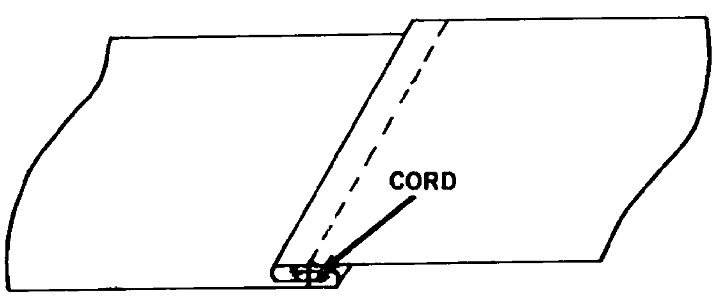
[1]Note: Chemical simulators refer to selected liquids which possess physical properties similar to active chemical warfare agents.

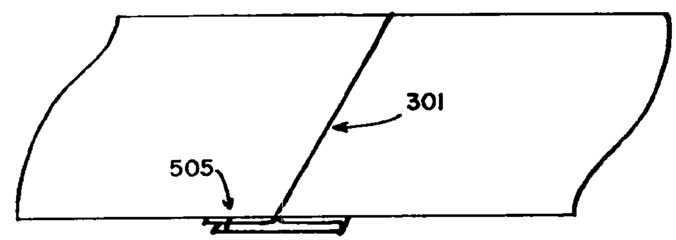


a. CORD SUPERIMPOSED ON SEAM

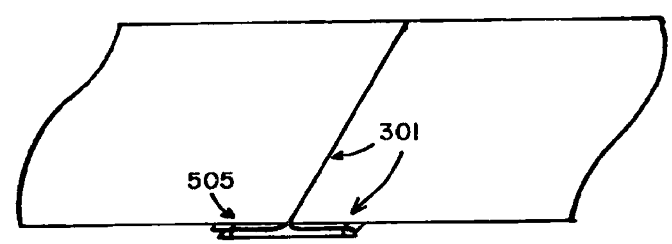


b. CORD SEWN BETWEEN SEAM

Figure 1. LSc-1 with cord type of seams



a. 301 PLUS ONE ROW OF 505



b. 301 PLUS ONE ROW OF 505 AND ONE ROW OF 301

Figure 2. Modified SSa-1 seams of stitch type 301 plus stitch type 505

Threads

Before making a more intensive study of the LSc-1 seam, some knowledge was required about the behavior of chemical simulators on sewing threads (4). Various threads in rows of a 301 stitch type (1) were tested. The threads included all-cotton and 50% cotton/50% nylon, soft finished and Quarpel-treated; and 80% cotton/20% nylon with heat-dissipating, bonded, glacé, and soft finishes. Both Quarpel-treated threads resisted penetration by chemical simulators better than similar threads that had not been so treated; the Quarpel-treated 100% cotton thread appeared to provide the greatest protection against penetration, apparently by resisting liquid migration along the rows of stitching (Fig. 3). One of the outstanding characteristics of the Quarpel-treated threads was found to be their inherent ability to prevent the transfer of liquids from the exposed thread to the unexposed thread. The other threads did not do this.

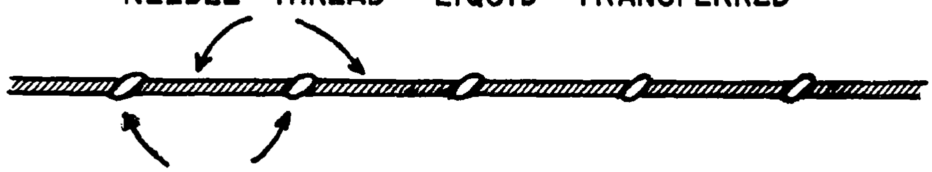


Figure 3. Observation of chemical simulators on 100% cotton Quarpel-treated thread.

This characteristic would appear to contradict the research previously cited (Ref. 11, p. 422), in which it was concluded that "each yarn intersection acts as a new reservoir to feed the branches equally."

Cords

Previous laboratory studies (3) had shown that a Hycar-treated Bemis cord stitched on and between the LSc-1 seams would resist the penetration of simulated chemical warfare agents. Similar studies using an unbleached cotton tying cord showed that this also would resist chemical simulators. Mandril and expulsion test methods promulgated by the Chemical Corps (6) were used for these studies.

Seams

In addition, experimental seams with cords were submitted to the Chemical Corps for their evaluation with liquid agents. The LSc-1 seam with an inserted Hycar-treated cord passed both the mandril and expulsion tests while a similar seam with the superimposed cord passed only the expulsion test, and failed the mandril.

In the present report, an attempt has been made to relate the performance of cords sewn on fabric to the measurements of their observed capillarity and absorption characteristics when exposed to chemical simulators. Water was used not only as the point of reference but also to indicate what might be expected when seams of CB-protective overgarments are subjected to moist environments under actual field conditions. It was hoped that the performance of the liquids on the cords would provide information that would aid in determining whether migration (15) and absorption of the liquids are desirable.

2. Experimental Materials and Procedures

Seams were made with 50/3 Quarpel-treated cotton thread, shade S-1, on a double layer of cotton warp/nylon filling 5-oz Quarpel-treated oxford, shade OG 107, using type 301 stitching and employing five types of cords coded as follows:

Code	Cord	Color	Wt. (yds/lb)	Diameter (cm)
A	Cotton tying cord	Greige	288	3.0
B	Cotton roving with loose braid (upholstery piping)	Greige	113	5.0
C	Rayon parachute braid	White	47	7.0x3.0
D	Rayon braid with cotton core (trimming braid)	White	208	2.5
E	Polyester tent cord	White	49	4.5

The following liquid chemical simulators were applied to the seams and also to the cords:

Code	
I	Water
II	Dimethyl hydrogen phosphite
III	Diethyl phthalate
IV	Bis (2-ethylhexyl) hydrogen phosphite

Three methods of application were followed:

1) First, the sewn cords were laid out horizontally with no extraneous pressure or tension. Each sample received at the center of the cord one drop (from an eyedropper) of each of the chemical simulators. The drop was applied from a height of 1/8 inch above the upper surface of the cord. The time for the liquids to disappear was measured (with a stop watch) from the time the drop reached the cord. After all the samples had been timed the lengthwise spread of the absorbed liquids through the cords was determined.

2) Each of the unsewn cords was then tested for rate of liquid migration over a length of 10 centimeters. The cords were suspended horizontally and fed a constant supply of the liquids. The time for the liquids to migrate over each centimeter of length was noted.

3) Finally, a 5-inch length of each cord was soaked in the liquids for 5 minutes and then drained on blotting paper for approximately 10 seconds. The rate of desorption was determined by noting the <u>weight</u> before immersion and at periodic intervals thereafter. The percentage of shrinkage was determined by taking <u>lengthwise measurements</u> of the cords initially, after soaking, and 4 hours after soaking.

3. <u>Results and Discussion</u>

a. <u>Penetration and migration of liquid on sewn cords</u>

The time for one drop of the liquid to disappear from the surface of the sewn cords is given in Appendix A and the lengthwise spread of one drop of the liquid through the sewn cords is given in Appendix B. The data from these tables are graphically represented in Figures 4 and 5, respectively.

These measurements were made instead of calculations that might have been made based on the theoretical equations outlined by Fox and Zisman (2) and Minor (9). From the speed with which most of the liquid drops disappeared (less than 3.8 seconds), one may conclude that contact angle measurements would be difficult to ascertain.

As seen in Appendix A, the two greige cotton cords (<u>A</u> and <u>B</u>) repelled the water (Liquid I) at once and held off the dimethyl hydrogen phosphite (Liquid II) for 75 and 45 <u>minutes</u> respectively (whereas both of these liquids disappeared, i.e., penetrated, in only a matter of <u>seconds</u> from the other cords C, D and E). However, on both of these cords (A and B), Liquid II went through the stitching line to the underside of the fabric, although in mandril and expulsion tests of similar samples none of the liquids penetrated the line of stitching.

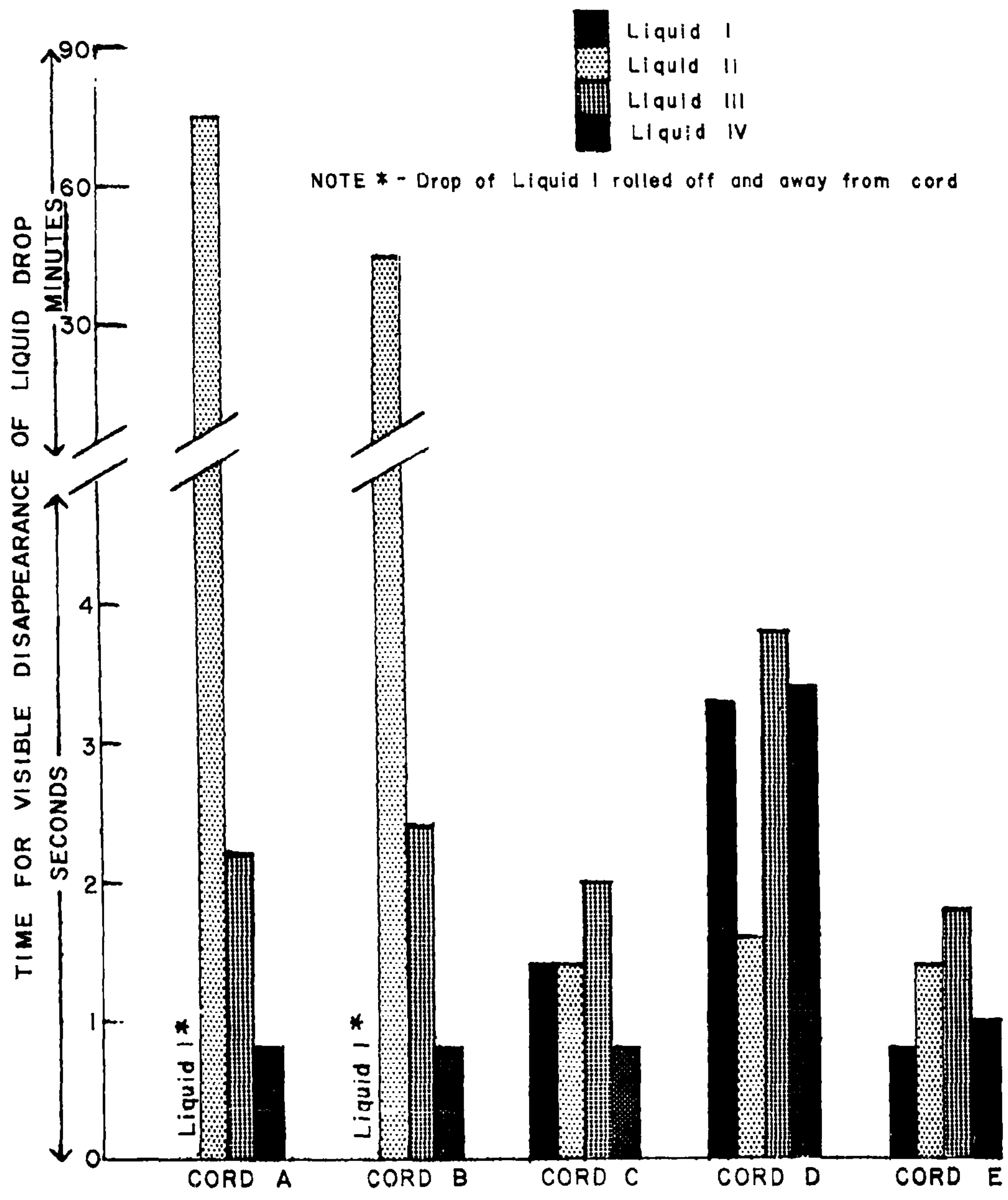


Figure 4. Time for visible disappearance of liquid drop

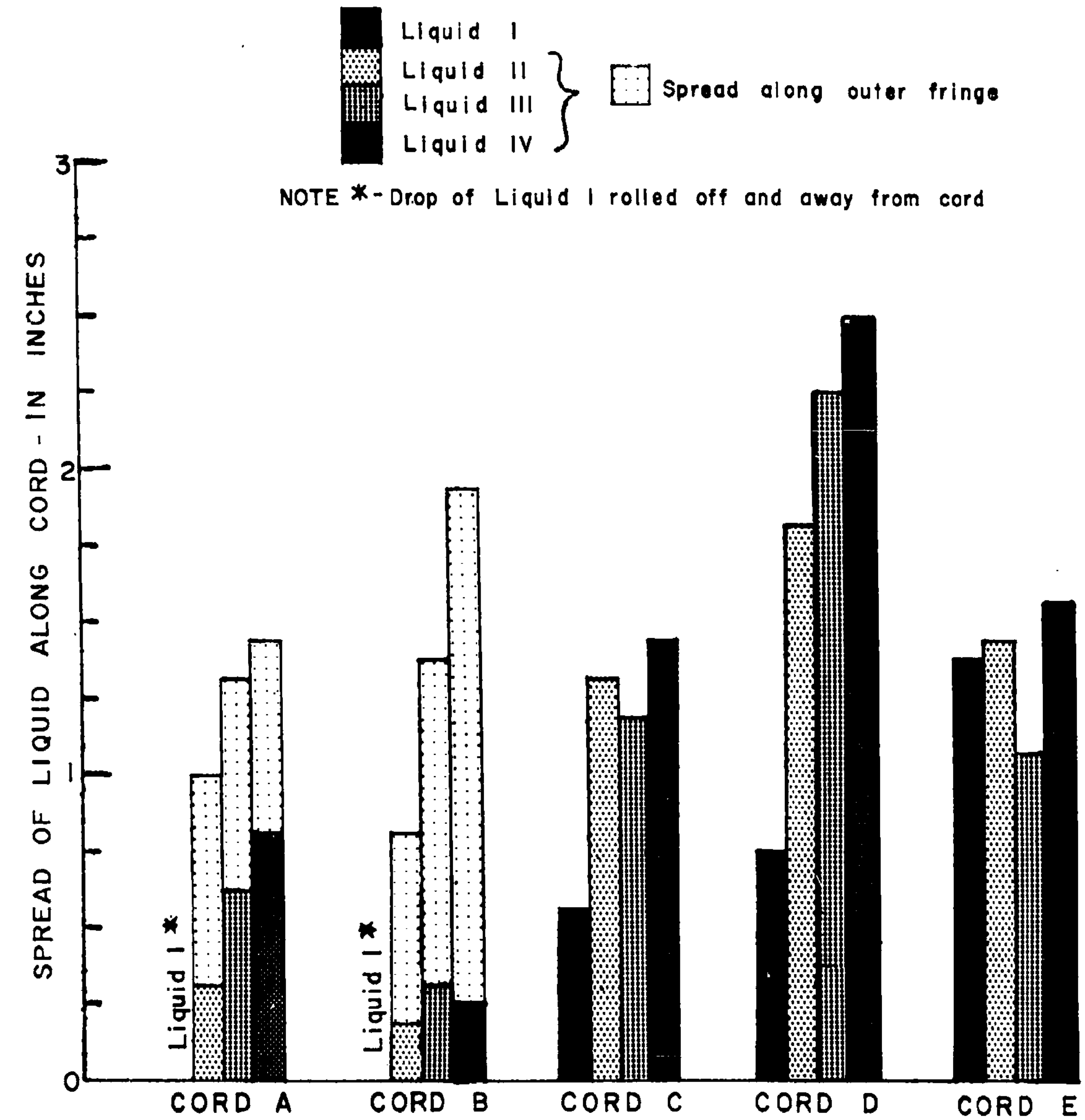


Figure 5. Spread of liquid along cords

This variance in performance may be explained by a difference in the tension or pressure imposed upon the samples. Without extraneous tension or pressure, the dimethyl hydrogen phosphite (Liquid II) appears to be absorbed by the fibers of the cord, permitting the liquid to pass through the line of stitching. Under tension and pressure, as in the mandril and expulsion tests, some migration of the liquid appears to occur and this tends to prevent the liquid from passing through the line of stitching.

The rayon and cotton trimming braid (D) appears to have taken longer and to have spread out more of Liquids III and IV than the other cords. This may be partially explained by its smaller diameter which provides less area than the other cords for liquid passage.

The polyester tent cord (E) illustrates a relatively quicker and also a more extensive spread of the liquids than the other cords except cord D with Liquids II, III and IV. Polyester fibers are hydrophobic, therefore the rapid migration of liquids through cord E is primarily a capillary function created by its tight and compact braid structure.

From the data of Appendices A and B, it is seen that cords sewn on a fabric vary in their ability to disperse a drop of liquid. It is also seen that liquids vary in their physical properties, as indicated by the differences in the time required to disappear and the area of spread over any one cord. Some of the factors which undoubtedly contributed to the variations in the observed behavior of the cords are their differences in surface configuration and finish and the resultant effect on their free surface energy. Previous research (12 and 7) has called attention to these influences as well as those of pore size and inherent fiber properties. Probably the comments made by Winch (16), and mentioned in the Introduction to this report in which he cautioned against the use of testing methods that might rank various media incorrectly for end-use application, should be kept in mind.

b. Rate of migration on unsewn cords

Appendix C shows the rate of liquid migration (from a constant supply of liquids) over measured lengths of the unsewn cords. Figure 6 graphically illustrates the migration.

The cotton cords A and B strongly resisted the migration of Liquid I (water), while the rayon cords C and D allowed a delayed migration of water. The polyester cord E showed a rapid migration of water, illustrating passage by means of a system of tight capillaries rather than by absorption by the fibers. It might be expected, therefore, that cord E would not perform satisfactorily under wet field conditions.

Cord B, and to some extent cord A, resisted the migration of Liquid II (dimethyl hydrogen phosphite). However, cords C, D, and E all showed patterns of a rather rapid migration of Liquid II.

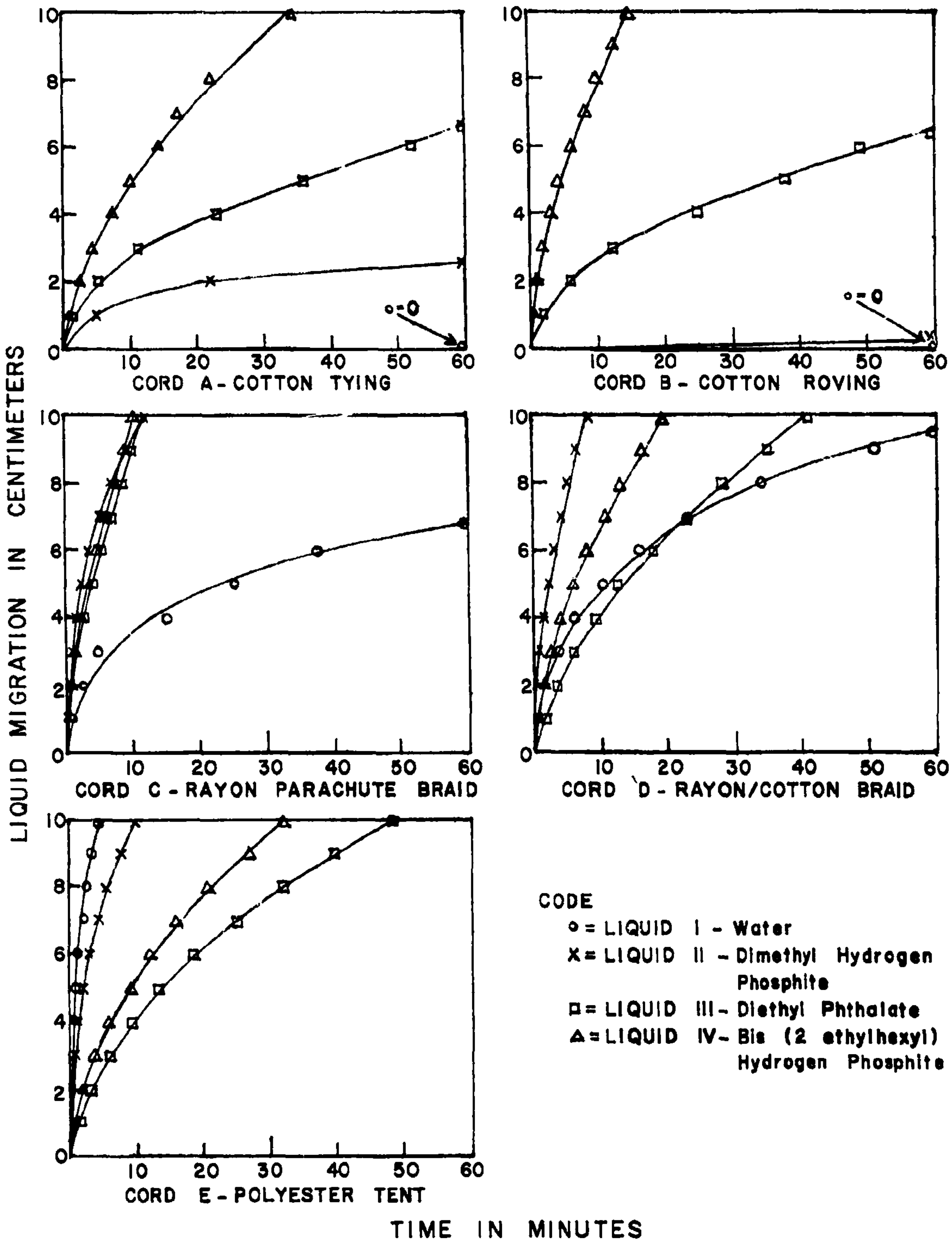


Figure 6. Rate of liquid migration

Cords A and B permitted Liquid III (diethyl phthalate) to migrate slowly, cord C showed the most rapid migration and cords D and E both showed slower migration of this liquid.

Cords A and E showed a slightly delayed migration of Liquid IV (bis (2-ethylhexyl) hydrogen phosphite), cords B and D showed a more rapid migration, while cord C showed the most rapid migration--similar to that for Liquids II and III. From its behavior on the cotton cords, Liquid IV appears to serve as a wetting agent.

c. Rate of desorption for unsewn cords

Appendix D gives the initial (original) weights of the cords, their weights after soaking 5 minutes and draining 10 seconds and at periodic intervals thereafter. The percent of weight increase from the original is also included. Figure 7 shows these data graphically.

The desorption rates clearly show the non-volatility of Liquids II, III, and IV. Evaporation of Liquid I (water), on the other hand, was completed within 4 hours in all the cords except cord C. Segal's hypothesis (13) that the volatility of a liquid is an important factor for wetting is not borne out by these findings. However, volatility may not be too closely related to the behavior of some of the toxic liquids.

The cotton cords A and B and the polyester cord E held negligible amounts of Liquid I (water). Cords A and especially B held appreciable amounts of Liquids II, III, and IV. The cotton cords A and B held more of Liquid II (dimethyl hydrogen phosphite) than did cords C, D, and E, yet A and B when tested with a drop of this liquid previously had shown leakage through the line of stitching. This may substantiate the thinking that migration as well as absorption may be a desirable characteristic for cords to be used in seams of CB protective overgarments.

The polyester cord E held the smallest amount of each of the liquids, except water on cords A and B. It will be remembered that this cord showed rapid migration of the liquids but no absorption within the fibers.

d. Shrinkage of unsewn cords

Appendix E shows the original length of the cords and the percentage of the original length after soaking 5 minutes in the liquids and after 4 hours of drying.

It will be seen that after immersion in water (Liquid I) all the cords except the polyester (E) shrank. The rayon parachute braid (C) showed the greatest amount of shrinkage in Liquid I (17%). The remaining cellulosic cords (A, B, and D) showed some shrinkage in water; after 4 hours drying, the shrinkage of cords B and D amounted to only 2 percent.

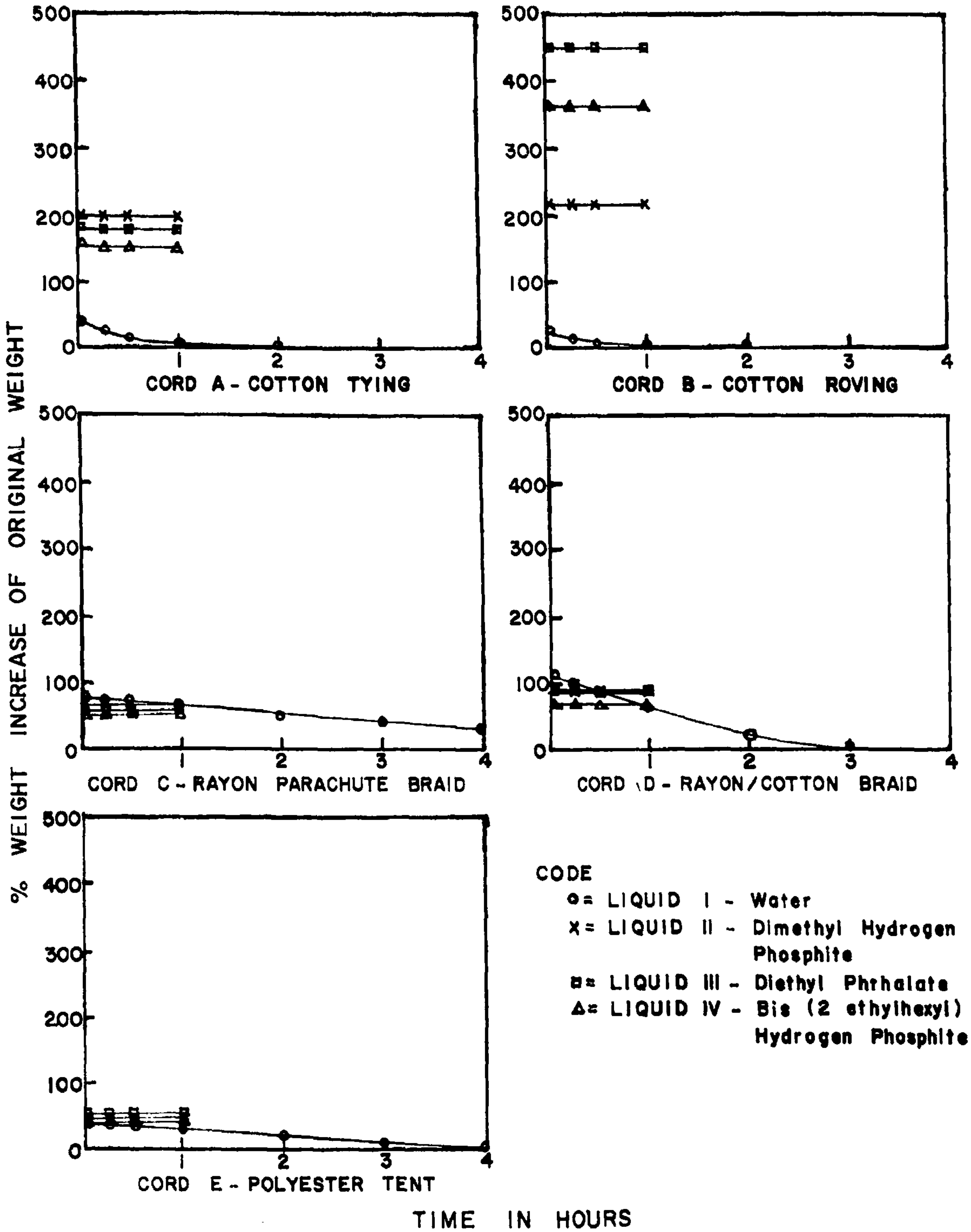


Figure 7. Rate of liquid desorption

Cord A shrank 5 percent after soaking in Liquid I and drying for 4 hours and shrank 4 percent after immersion in Liquid II and drying. It would appear from the results with Liquid I that, because of its excessive shrinkage alone, the rayon parachute braid (cord C) would provide the least satisfactory service when sewn into the seams of a garment.

4. Conclusions

From this study of the behavior of liquids on cords, the following conclusions may be drawn:

a. Cords in an LSc-1 seam will provide protection against leakage of chemical simulators through the line of stitching. Further evaluation by the Chemical Corps of seams with cords has confirmed that these seams will resist penetration by the liquid agents.

b. The chemical simulators used differed in their migration through and absorption by the five cords studied.

c. The cords used differed in their behavior in regard to the chemical simulators.

d. A cord that possesses both migration and absorption properties can be effective in providing protection in the seams of CB protective overgarments. If the cord is constructed with an absorbent inner cord covered with a braid-like construction of synthetic fibers, there would be increased migration of liquids as well as absorption.

e. Cords in seams must be further tested in order to relate their performance with the realistic conditions that may be expected from CB overgarments under actual field conditions. More knowledge must be obtained not only about the behavior of toxic liquid agents on the fibers and structures of the cords which may be used in the seaming of these garments but also about the wear and abrasion resistance of the textiles which may be used.

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APPENDIX A

TIME FOR VISIBLE DISAPPEARANCE OF LIQUID DROP FROM SEWN CORD
(in seconds unless otherwise noted)

	Sewn Cord				
Liquid	A	B	C	D	E
I	0*	0*	1.4	3.3	0.8**
II	75 min.***	45 min.***	1.4	1.6	1.4
III	2.2	2.4	2.0	3.8	1.8
IV	0.8**	0.8**	0.8**	3.4	1.0

* Drop rolled off and away from cord
** Minimum time required to start and stop stopwatch
*** Liquid went through stitching to underside of fabric

APPENDIX B

SPREAD OF LIQUID ALONG SEWN CORDS
(in inches)

	Cord				
Liquid	A	B	C	D	E
I	0*	0*	9/16	12/16	1-6/16
II	5/16 to 1	3/16 to 13/16	1-5/16	1-13/16	1-7/16
III	10/16 to 1-5/16	5/16 to 1-6/16	1-3/16	2-4/16	1-1/16
IV	13/16 to 1-7/16	4/16 to 1-15/16	1-7/16	2-8/16	1-9/16

Note: The 2-figure range denotes the mass of Liquids II, III, and IV spread on the cords A and B and the spread along the outer fringes.

* Drop rolled off and away from cord

APPENDIX C

RATE OF LIQUID MIGRATION THROUGH UNSEWN CORDS

(Distance) (cm)	Cord A min.	A sec.	B min.	B sec.	C min.	C sec.	D min.	D sec.	E min.	E sec.
					Liquid I					
1	60	0	60	0	0	30	0	25	0	03
2	-		-		2	15	1	30	0	09
3	-		-		4	45	3	40	0	20
4	-		-		15	0	6	15	0	35
5	-		-		25	0	10	15	1	0
6	-		-		37	30	15	45	1	25
7	-		-		60	0	23	30	2	05
					(6.8 cm)					
8	-		-		-		34	0	2	45
9	-		-		-		51	0	3	35
10	-		-		-		60	0	4	30
							(9.6 cm)			
					Liquid II					
1	5	0	60	0	0	10	0	08	0	10
			(0.25 cm)							
2	22	0	-		0	30	0	30	0	30
3	60	0	-		0	55	0	55	0	55
4	-		-		1	30	1	30	1	30
5	-		-		2	15	2	10	2	20
6	-		-		3	30	3	05	3	15
7	-		-		5	15	4	05	4	30
8	-		-		6	45	5	20	5	50
9	-		-		9	20	6	40	7	45
10	-		-		11	30	8	35	10	0
					Liquid III					
1	1	30	1	30	0	25	1	30	1	30
2	5	10	6	0	1	0	3	10	3	20
3	11	0	12	0	1	50	6	0	6	0
4	23	0	25	30	2	45	9	10	9	0
5	36	0	38	0	3	55	12	30	13	15
6	52	0	49	30	5	15	17	30	18	30
7	60	0	60	0	6	35	22	45	25	0
	(6.3 cm)		(6.3 cm)							
8	-		-		8	0	28	0	32	0
9	-		-		9	40	35	0	39	45
10	-		-		11	45	41	0	48	45

APPENDIX C (continued)

RATE OF LIQUID MIGRATION THROUGH UNSEWN CORDS

(Distance) (cm)	A min.	A sec.	B min.	B sec.	C min.	C sec.	D min.	D sec.	E min.	E sec.
					Liquid IV					
1	0	45	0	15	0	20	0	35	0	35
2	2	30	0	45	0	55	1	25	2	0
3	4	10	1	30	1	35	2	30	3	40
4	7	30	2	40	2	25	4	0	5	45
5	10	15	3	55	3	30	6	0	9	0
6	14	10	6	20	4	45	8	0	11	50
7	17	15	8	15	5	50	10	30	15	50
8	22	15	9	40	7	20	13	0	20	45
9	-		12	15	8	30	16	15	27	0
10	35	0	15	20	10	10	19	40	32	15

Note: Cord C swelled when wet and tightened the unwetted portion of braid

APPENDIX D

RATE OF DESORPTION OF LIQUIDS FROM UNSEWN CORDS

Time* (min.)	A Wt (gm)	A Incr (%)	B Wt (gm)	B Incr (%)	C Wt (gm)	C Incr (%)	D Wt (gm)	D Incr (%)	E Wt (gm)	E Incr (%)
Liquid I										
(Original Cord	0.22	0	0.56	0	1.30	0	0.30	0	1.30	0)
0	0.31	41	0.67	26	2.43	79	0.63	110	1.81	39
5	0.30	36	0.65	23	2.37	74	0.61	106	1.79	38
10	0.29	32	0.63	19	2.35	73	0.60	100	1.78	37
15	0.28	27	0.61	15	2.34	72	0.59	97	1.76	35
30	0.25	14	0.58	9.4	2.30	69	0.57	90	1.72	32
60	0.23	4.5	0.55	3.8	2.23	64	0.51	70	1.67	28
120	0.22	0	0.53	0	2.08	53	0.37	23	1.56	20
180	-	-	-	-	1.95	43	0.30	0	1.42	9.2
240	-	-	-	-	1.80	32	-	-	1.32	1.5
Liquid II										
(Original Cord	0.21	0	0.56	0	1.30	0	0.30	0	1.30	0)
0	0.64	205	1.76	214	2.30	70	0.56	87	1.91	47
5	0.63	200	1.76	214	2.30	70	0.56	87	1.91	47
10	0.62	195	1.76	214	2.25	67	0.56	87	1.90	46
15	0.62	195	1.76	214	2.24	66	0.56	87	1.90	46
30	0.62	195	1.76	214	2.24	66	0.56	87	1.90	46
60	0.62	195	1.76	214	2.24	66	0.56	87	1.90	46
120	-	-	-	-	-	-	-	-	-	-
180	-	-	-	-	-	-	-	-	-	-
240	-	-	-	-	-	-	-	-	-	-
Liquid III										
(Original Cord	0.21	0	0.54	0	1.29	0	0.30	0	1.30	0)
0	0.59	181	2.95	447	2.14	57	0.56	87	1.96	52
5	0.58	176	2.95	447	2.14	57	0.56	87	1.94	50
10	0.58	176	2.95	447	2.14	57	0.56	87	1.94	50
15	0.58	176	2.95	447	2.14	57	0.56	87	1.94	50
30	0.58	176	2.95	447	2.14	57	0.56	87	1.94	50
60	0.58	176	2.95	447	2.14	57	0.56	87	1.94	50
120	-	-	-	-	-	-	-	-	-	-
180	-	-	-	-	-	-	-	-	-	-
240	-	-	-	-	-	-	-	-	-	-

* See footnote next page

APPENDIX D (continued)

RATE OF DESORPTION OF LIQUIDS FROM UNSEWN CORDS

Time* (min.)	Cord A Wt (gm)	A Incr (%)	B Wt (gm)	B Incr (%)	C Wt (gm)	C Incr (%)	D Wt (gm)	D Incr (%)	E Wt (gm)	E Incr (%)
					Liquid IV					
(Original Cord	0.22	0	0.55	0	1.30	0	0.30	0	1.30	0)
0	0.57	159	2.55	364	2.08	55	0.49	63	1.83	41
5	0.56	154	2.55	364	2.05	53	0.50	67	1.80	38
10	0.55	150	2.55	364	2.05	53	0.50	67	1.80	38
15	0.55	150	2.55	364	2.05	53	0.50	67	1.80	38
30	0.55	150	2.56	366	2.05	53	0.50	67	1.79	38
60	0.55	150	2.56	366	2.05	53	0.50	67	1.79	38
120	-	-	-	-	-	-	-	-	-	-
180	-	-	-	-	-	-	-	-	-	-
240	-	-	-	-	-	-	-	-	-	-

* Cord soaked 5 minutes, then drained 10 seconds on blotting paper, then weighed at the specified intervals up to 4 hours.

APPENDIX E

SHRINKAGE OF UNSEWN CORDS

	Cords				
	A	B	C	D	E
			Liquid I		
Original length, inches	5	5	5	5	5
Percent of original length:					
Immediately after soaking	93	94	83	95	100
After soaking and 4 hrs drying	95	98	83	98	100
			Liquid II		
Original length, inches	5	5	5	5	5
Percent of original length:					
Immediately after soaking	99	100	100	100	100
After soaking and 4 hrs drying	96	100	100	100	100
			Liquid III		
Original length, inches	5	5	5	5	5
Percent of original length:					
Immediately after soaking	100	99	100	100	100
After soaking and 4 hrs drying	100	100	100	100	100
			Liquid IV		
Original length, inches	5	5	5	5	5
Percent of original length:					
Immediately after soaking	100	100	99	100	100
After soaking and 4 hrs drying	100	99	100	100	100

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